IL NUOVO CIMENTO Vol. 35 C, N. 1 Gennaio-Febbraio 2012
DOI 10.1393/ncc/i2012-11145-5

Colloquia: LaThuile11

Status of the SuperB project

G. Wormser
LAL, Univ Paris-Sud, CNRS/IN2P3 - Orsay, France

(ricevuto il 29 Settembre 2011; pubblicato online il 25 Gennaio 2012)

Summary. — The SuperB project is a very ambitious program whose goal is to build, in the immediate vicinity of the Frascati National Laboratory, an e^+e^- collider operating in the $\Upsilon(4S)$ region with a luminosity in excess of $10^{36}\,\mathrm{Hz/cm^{-2}}$, surpassing by two orders of magnitude the present generation. Such a progress has ben made possible by the new Crab Waist colliding scheme together with the design of very low emittance rings. The physics goal of this machine is to determine the structure of the new physics (NP) at the Terascale that is likely to show up at the LHC. This will be possible through a very detailed scrutiny of all NP induced indirect effects in rare (or even forbidden in the Standard Model) decays and precision measurements in the quark and lepton sectors. The project, an official element of the European HEP Strategy, has been recently approved and fully funded by the Italian government. The Nicola Cabibbo Laboratory will be created as a consortium to host and manage the project. The site has been selected and the detector collaboration is currently being formed. The first beams are expected in 2016, with a yearly integrated luminosity of $15\,\mathrm{ab^{-1}}$.

PACS `11.30.Er` – Charge conjugation, parity, time reversal, and other discrete symmetries.
PACS `11.30.Hv` – Flavor symmetries.
PACS `13.35.-r` – Decays of leptons.
PACS `29.20.-c` – Accelerators.

1. – Introduction

All major discoveries concerning the flavour sector have, as strange as it may seem, been first made by indirect observations. The existence and properties of the 4th, 5th and 6th quarks have been demonstrated a few years before their direct observations through the non-observation of neutral currents reactions (GIM mechanism), CP violation in the K sector (KM hypothesis), rate of the B mixing. These indirect measurements not only provided information on the existence and mass of these quarks but also on the organisation of the quark sector in the Standard Model. The SuperB project goal is to repeat this brilliant history but now for the New Physics Beyond the Standard Model (BSM or NP). There is good hope that this approach will be very successful since we

	Observable/mode	H^+ high $\tan\beta$	MFV	non-MFV	NP Z penguins	Right-handed currents	LTH	SUSY AC	RVV2	AKM	δLL	FBMSSM
✓	$\tau \to \mu\gamma$							★★★	★★★	★	★★★	★★★
✓	$\tau \to \ell\ell\ell$						★★★					
✓	$B \to \tau\nu, \mu\nu$	★★★(CKM)										
✓	$B \to K^{(*)+}\nu\bar{\nu}$			★	★★★			★	★	★	★	★
✓	S in $B \to K_S^0\pi^0\gamma$					★★★						
✓	S in other penguin modes			★★★(CKM)		★★★		★★★	★★	★	★★★	★★★
✓	$A_{CP}(B \to X_s\gamma)$			★★★		★★		★	★	★	★★★	★★★
✓	$BR(B \to X_s\gamma)$		★★★	★		★						
✓	$BR(B \to X_s\ell\ell)$			★	★	★						
✓	$B \to K^{(*)}\ell\ell$ (FB Asym)							★	★	★	★★★	★★★
	$B_s \to \mu\mu$							★★★	★★★	★★★	★★★	★★★
	β_s from $B_s \to J/\psi\phi$							★★★	★★★	★★★	★	★
✓	a_{sl}						★★★					
✓	Charm mixing							★★★	★	★	★	★
✓	CPV in Charm	★★									★★★	

Fig. 1. – (Colour on-line) List of golden mode channels for SuperB and their relevance for various New Physics Models. The modes with a red tick are accessible to SuperB, the ones without are only available with hadron machines.

already know that strong constraints already exist when building any BSM model to avoid producing effects in the flavour sector in contradiction with current observations. The detailed understanding of the unknown physical source of these constraints and the identification of the BSM model that Nature has chosen to implement is the ultimate goal of SuperB. This task will be made easier when LHC will have discovered some new particles in the mass range between 200 GeV and 1 TeV, because this will precisely set the mass scale for the indirect effects induced by this new particle at SuperB. The requirement which was used to specify the integrated luminsoty needed for the SuperB physics case is that a 3 σ effect should be detected at SuperB in one of the accessible channels for a 1 TeV particle given the fact that its couplings phase should be at minimum the SM phase (its couplings cannot be lower as is explained in the so-called Minimum Flavour Violation scheme). The minimum integrated luminosity to reach this goal is $75\,\text{ab}^{-1}$, which can be recorded in 5 years of data taking at SuperB.

2. – SuperB physics goals

The general goal of the SuperB physics program is to understand in depth the underlying structure of the new physics (NP) beyond the Standard Model (BSM). It has been demonstrated in great detail [1] that by measuring deviations from SM expectations in a variety of different channels, one could gather very precious information about the structure of the NP. This is because all new particles with masses below 1 TeV will generate deviations from SM even if their couplings to normal quarks and leptons is minimum. Figure 1 shows the relative sensitivity of the key superB observables with respect to various theoretical frameworks. Several lessons can be learned from this figure: firstly, the golden channels lists must be quite comprehensive to be able to disentangle all the various scenarios; secondly that this golden channel list contains many modes that are only accessible to a SuperB factory. Some modes will be well measured by the LHCb experiment which will have completed its first data taking phase when SuperB will start and integrated around $5\,\text{fb}^{-1}$, as can be seen from fig. 2 but many others just cannot be measured at all (or not measured with the needed precision) without SuperB because they

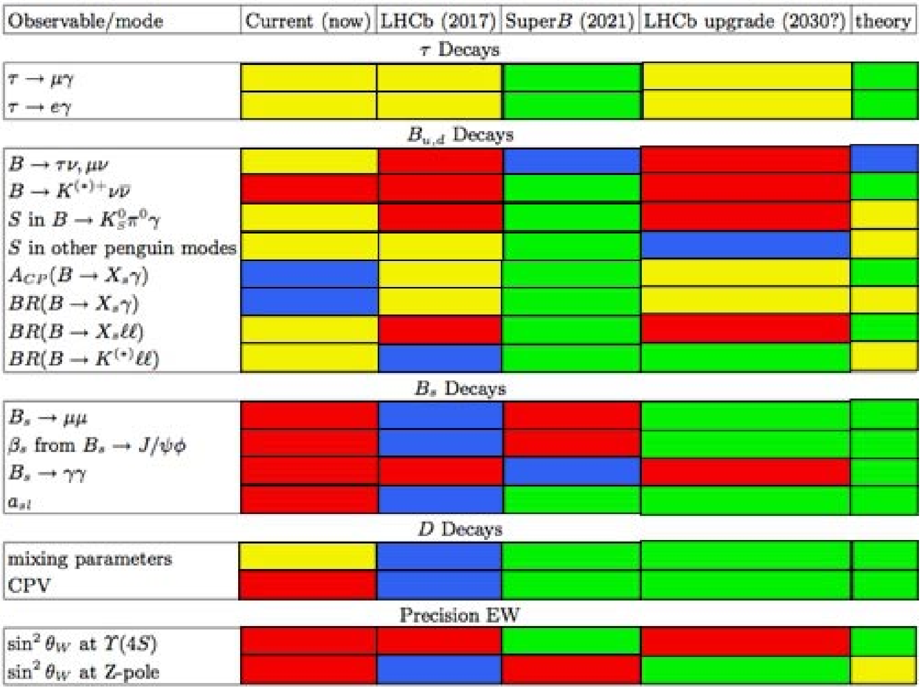

Fig. 2. – (Colour on-line) Sensivity of SuperB and LHCb to various physics modes. The colour code is as follows. Red: no measurement, yellow: not precise, blue: precise, green: very precise. For the theory column, the color code is: yellow: moderately clean mode, blue: clean mode but requires lattice computations, green: very clean mode

involve one or more neutrinos and are based on inclusive measurements. The rightmost column of this table indicates in green the modes which can be best predicted in the SM framework, and which therefore can be the best candidates for unambiguous deviations from SM predictions. There is a strong correlation between these clean modes and the moes who can be accessed only by SuperB. It has to be noted that the physics program of SuperB is not restricted to the study of B decays at the Υ(4S) resonance. The search for lepton flavour violation is one of the major physics goals and the present limits on the decay $\tau \to \mu\gamma$ and τ to three charged leptons can be improved by a factor 10, reaching BR level from 10^{-9} to a few 10^{-10} becoming quite competitive and complementary with the related search $\mu \to e\gamma$. A key asset in this search is the fact that SuperB will benefit of an 80% polarized electron beam. This will allow the search for $\tau \to \mu\gamma$ to benefit from a very significant background rejection. This extra factor will be quite important since many NP models predict BR for such very rare decays in the 10^{-9} range. The beam polarization also offers the possibility to perform search for CP violation in τ decays, and to try to perform the first measurement of τ magnetic moment. In addition to this key role in the lepton sector, the beam polarization will allow to measure the $\mu^+\mu^-$ forward-backward asymmetry at 10 GeV, adding a measurement of comparable precision to the one performed at LEP. This will again allow a good sensitivity to NP. Another feature of the SuperB physics program is to run at charm thresold with asymmetric beam energies, giving access for the first time to time-dependant CP asymmetries in the charm sector. The very high luminosity (10^{35}) foreseen at 4 GeV will allow unprecedented precision in the charm sector.

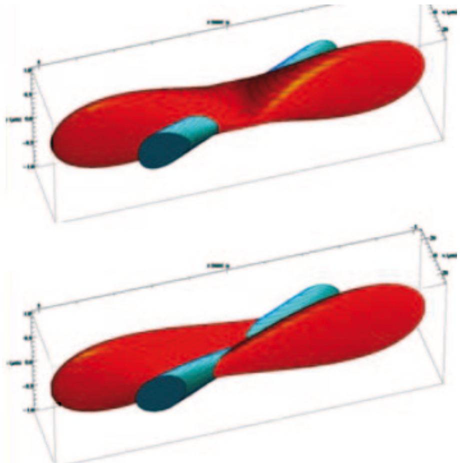

Fig. 3. – Profiles of the two colliding beams witout (top) and with (bottom) Crab Waist scheme. The predistortion of the beams allow the minimum waist of one beam to be aligned with the other.

3. – The SuperB accelerator

The SuperB accelerator concept stems from a series of very innovative ideas developed in the accelerator community in the last ten years. Previous experience with PEP-II and KEKB rings showed it would be extremely difficult to increase in a significant manner the beam currents. Therefore the only solution left to reach 10^{36} luminosity is to collide nanometer size beam. This requires the production of extremely low emittance beams in the electron and positron sources and in the linac, the low emittance conservation in the rings and the design a final focus system capable to generating and putting in stable collisions 50 nm vertical size beams.This has been made possible in particular thanks to the development of the all the accelerator R&D performed in the framework of the International Linear Collider project where the issues are exactly the same. One must also point out that SuperB rings have also benefitted from the development of very high-brilliance 3rd-generation light sources. But the collision of such dense beams creates, if no counter measures are taken, very large beam-beam resonances which will immediately blow up the beams. The Crab Waist scheme, which consists in the addition of two sextupoles very near the Interaction point, has been precisely invented by Pantaleo Raimondi [2] in order to suppress these beam-beam effects by predistorting the beams before the collision in order to minimize the beam-beam effects. The effect of the Crab Waist sextupoles of the beam profiles are displayed in fig. 3. The tune space, which was previously heavily populated by beam killing resonances, offers now very large resonance-free zones (see [3], p. 54). The crab waist scheme was very successfully demonstrated on the DAFNE storage ring in 2008-2009 [4]. DAFNE luminosity has been increased by a factor 3 compared to the absence of sextupoles, as predicted by the simulations. It is often asked how to compare this sizable but modest gain with the factor 100 expected between SuperB and present colliders. As mentioned above, the very large luminosity increase will be due to the very small size of the beams, going from micrometer to nanometer vertical size. The Crab waist technique is the key enabling factor, making possible the collision of such dense beams without detrimental beam-beam effects.

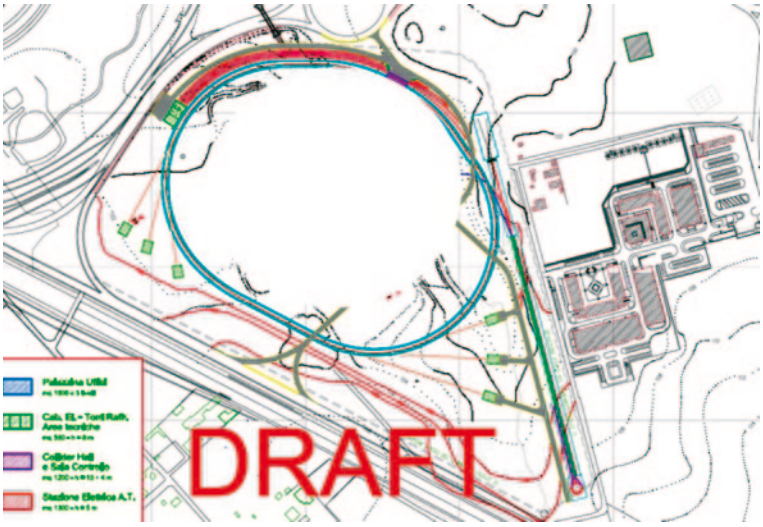

Fig. 4. – Layout of the SuperB accelerator on the Tor Vergata site (preliminary).

The detailed description of the accelerator design has been recently updated and is described in [3]. The preliminary layout of the accelerator on the SuperB site (see below) is indicated on fig. 4. It consists of a polarized electron source, a high-yield positon source coupled to a positron damping ring, a 7 GeV Linac and of two 1250 m rings. As a result of the partnership with the Italian Institute of Technology, SuperB rings will also be used to produce top class synchrotron beam lines. Six such beam lines are tentatively indicated on fig. 4, located on the High-Energy Ring, since 7 GeV light sources are much more difficult to find than 4 GeV ones. The brilliance of such beamlines will be higher than any other presently running machine, given the very low emittance and relatively high current (2 A) of the Super B ring (see [3], p. 144).

4. – The SuperB site

Given the revolutionnary character of the SuperB machine, no present ring or tunnel in Europe is capable of hosting the SuperB project. It has been therefore necessary to explore green field scenarios. The SuperB project has issued a Site Specifications document, which has been reviewed by an international Site Committee. The specifications adress the following issues: site size given the machine circumference (1250 meters), the space needed for synchrotron beam lines, and office and utility spaces, geology, vibration level, constructibility, ease of access for people and components, availability of energy and cooling, proximity of a nearby INFN structure, industrial expertise level in the vicinity. A clear desire has also been expressed towards a site allowing a shallow tunnel since the presence of several synchrotron light beamlines make this possibility extremely cost effective. Although several site candidates have been identified throughout Italy, the INFN management indicated its marked preference for a site in the immediate vicinity of the Frascati National Laboratory where the accelerator design team is located. Two sites have been finally considered, the LNF site itself wheer the machine has to be deeply underground given the strong slopes on this site and the nearby Tor-Vergata University site (fig. 4). The geological structure of Tor Vergata is very favorable because of its flat-

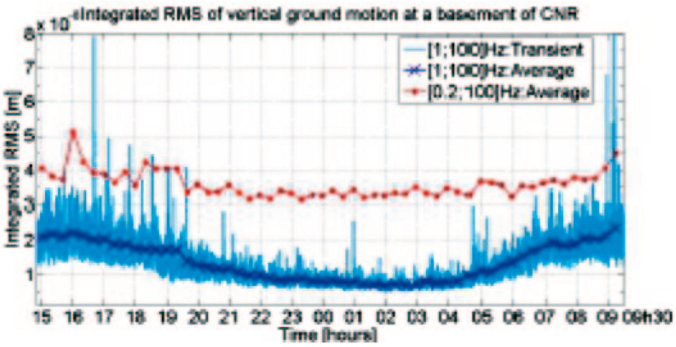

Fig. 5. – Long-term measurement of the RMS vertical displacement at a point on Tor Vergata site, close to the future SuperB Interaction Region. The RMS varies between 10 and 20 nm, when the noise is integrated between 1 and 100 Hz.

ness, uniformity and the good vibration damping properties of the pyroclastic material. A intensive vibration measurement campaign has been performed by the LAPP Annecy team and the results show that the RMS vertical motion along the ring or at the IP is between 20 and 40 nm, much below the 300 nm required, in spite of the presence of the Rome-Naples highway 100 m away (fig. 5). Given all these nice properties (the site has also been checked against archeological remains), the Tor Vergata site has been formally selected and officially proposed by the Tor Vergata University to INFN for SuperB use. INFN has endorsed this proposal and therefore, the Tor vergata site has been definively selected as SuperB site.

5. – The SuperB detector

Since the BABAR and SuperB physics requirtements are very similar, the SuperB detector can and will reuse very significant parts of the BABAR detector in order to save costs and time, and because its very good properties: magnet, iron yoke, CsI(Tl)-based crystal calorimeter, and the quartz bars of the Particle IDentification system (PID). The overall structure of the SuperB detector shown in fig. 3 is therefore very similar to BABAR. However, sevral main differences exist. The much higher luminosity in SuperB will force the SuperB vertex detector to be much more radiation resistant both in terms of integrated dose and instantaneous occupancy than the BABAR one. In addition, the smaller boost (0.238 instead of 0.56) in SuperB forces the first SVT layer to be closer to the beam pipe, in order to retain a comparable or better proper time resolution. The SuperB physics program calls for a better Hermeticty of the detector because of the renewed importance of the mode involving one or two neutrinos in the final state. SuperB will therefore be equipped, budget permitting, of a forward PID device and of a backward calorimeter. These two additions will increase in total by 10% superB efficiency to the very rare modes described above. The detailed description of the SuperB detector can be found in [5, 6]. It is displayed in fig. 6.

Some modifications will be implemented on the parts coming from BABAR: the flux-return will be augmented with additional absorber to increase the number of interaction lengths for muons to roughly 7λ; the DIRC camera will be replaced by a twelvefold modular camera using multi-channel plate (MCP) photon detectors in a focusing con-

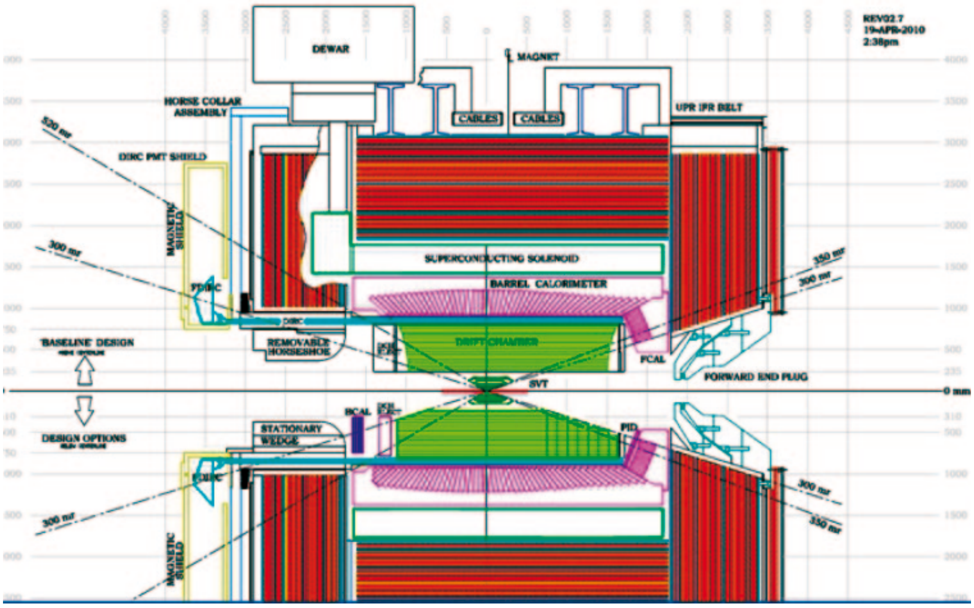

Fig. 6. – Cross section of the SuperB detector. the bottom part includes the two options considered to improve SuperB Hermiticity: a backward calorimeter and a forward PID device.

figuration using fused silica optics to reduce the impact of beam related backgrounds and improve performance; the forward EMC will feature cerium-doped LYSO (lutetium yttrium orthosilicate) crystals, which have a much shorter scintillation time constant, a lower Molière radius and better radiation hardness than the current CsI(Tl) crystals, again for reduced sensitivity to beam backgrounds and better position resolution.

The tracking detectors for SuperB will be new. To maintain sufficient proper-time difference (Δt) resolution for time-dependent CP violation measurements with the SuperB boost of $\beta\gamma = 0.24$, the vertex resolution will be improved by reducing the radius of the beam pipe, placing the innermost layer of the SVT at a radius of roughly 1.2 cm. This innermost layer of the SVT will be constructed of either silicon striplets or Monolithic Active Pixel Sensors (MAPS) or other pixelated sensors, depending on the estimated occupancy from beam-related backgrounds. Likewise, the design of the cell size and geometry of the DCH will be driven by occupancy considerations. The hermeticity of the SuperB detector, and, thus, its performance for certain physics channels will be improved by including a backwards veto-quality EMC detector comprising a lead-scintillator stack.

6. – The SuperB project status

Between December 2010 and May 2011, the SuperB project has succesfully cleared all the govermental milestones to become a fully funded project. SuperB has been ranked first among a list of 14 Flagship Projects forming the core of the 2011-2013 National Research Plan in Italy. This Plan has been approved by the government and voted at both Houses of the Italian Parliament in December 2010, together with a generic funding mechanism. This resulted in an immediate release of 19 M towards the construction of SuperB. The details of the SuperB funding, and especially its pluriannual investment profile have been recently endorsed by the interministerial CIPE committee. A budget of 50 M in 2011 has been allocated to the project. according to the INFN triennal plan indicated below. The scope of the SuperB project consisting of a HEP accelerator and a synchrotron light source, a consortium will be made within the following months between INFN, IIT (The Italian Institute of Technology, in charge of the light source sector), Tor Vergata University (mainly in charge of the civil construction on the site) and the Italian Ministry for Research. The decision has been taken to name this consortium Nicola Cabibbo laboratory. The intention of the Italian Governement is to make this structure evolve into an ERIC (European Research Infrastructre Consortium) in a few years. The Nicola Cabiboo Laboratory wil be very active to seek international partnerships for the construction of the SuperB accelerator.

7. – Conclusion

The launch of the SuperB project is a very rare and important event in European particle physics. Only once every 25 years or so, a large scale project is created in Europe besides the CERN projects, the last example of such an initiative being HERA in Hamburg. It is of course very clear that the concentration of European investments at CERN is essential, but the added diversity by such national or regional programs is also important and was recognized as such in the European Strategy document adopted in Lisbon in July 2006. The exceptional scientific and technological merits of the SuperB project make this new adventure particularly exciting. Recent decisive progress have been accomplished with the final approval and funding of the machine by the Italian Governnement, the final site selection on the campus of the Tor Vergata University, the decision to create the Nicola Cabibbo Laboratory consortium, the formal launch of the detector collaboration formation. In parallel to these major milestones, the detailed technical design of the accelerator, synchrotron light beam lines and detecor is taking place, with the publication of Technical Design Reports documents in 2012. Given all this activity, machine commissionning can be expected in 2016, in a time frame a little later but comparable to the similar program, SUPERKEKB and BELLE-II, being pursued in Japan. The competition with this project will be accompanied with a very substantive collaboration, as was already the case in the PEP-II/BABAR-KEKB/BELLE lifetime and will certainly turn out to be very fruitful. Major scientific breakthroughs, in terms of a deep understanding of the organisation of the physics beyond the Standard Model, in partnership with the LHC results, can therefore be confidently expected around 2020, when SuperB will have collected its nominal integrated luminosity of $75\,\mathrm{ab}^{-1}$.

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